APPARATUS AND METHODS FOR FORMING TORODIAL WINDINGS FOR CURRENT SENSORS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This Application is a continuation-in-part of U.S. Application No. 09/642,631, filed August 18, 2000, which, in turn, is a continuation-in-part of U.S. Application No. 09/152,145, filed September 11, 1998, which claims the benefit of U.S. Provisional Application No. 60/058,589, filed September 12, 1997, each of which application is herein incorporated by reference.

BACKGROUND

[0002] This invention relates generally to electricity meters and, more particularly, to toroidal winding assemblies for use in current sensing and to methods of making such assemblies.

[0003] Current sensors are used in many applications including residential and industrial electric power metering. These sensors typically include a toroidal winding assembly comprising at least one electrically conductive wire wound on a toroidal core. Typically, the core comprises iron or a laminated magnet-quality steel and has a square or circular cross-section. The wire coil that results has the same cross-section and the same generally toroidal shape as the core.

[0004] Among the factors contributing to the cost of making this assembly are: the cost of the core material itself; the need to machine the core within specified tolerances; and the difficulty of winding the wire on the pre-formed toroidal core while maintaining a tolerance on the spacing between adjacent winding loops. An opportunity exists, therefore, to lower the cost of such toroidal assemblies by substituting lower cost core materials and by finding an alternative coil winding scheme.

SUMMARY

[0005] In accordance with one embodiment of the present invention, a method of forming toroidal winding assemblies comprises: forming a longitudinal assembly having a first assembly end and a second assembly end; bending the longitudinal assembly to form a generally toroidal assembly; and bonding the first assembly end to the second assembly end to form the toroidal winding assembly.

DRAWINGS

[0006] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0007] Figure 1 is a perspective view of a longitudinal assembly in accordance with one embodiment of the present invention.

[0008] Figure 2 is a perspective view of a generally toroidal assembly in accordance with the embodiment of Figure 1.

[0009] Figure 3 is a perspective view of a toroidal winding assembly in accordance with the embodiment of Figure 1.

[0010] Figure 4 is a perspective view of the longitudinal assembly in accordance with another embodiment of the present invention.

[0011] Figure 5 is a side view of the longitudinal assembly in accordance with another embodiment of the present invention.

[0012] Figure 6 is a side view of the generally toroidal assembly in accordance with the embodiment of Figure 5.

[0013] Figure 7 is a side view of the toroidal winding assembly in accordance with the embodiment of Figure 5.

[0014] Figure 8 is a perspective view of the longitudinal assembly in accordance with another embodiment of the present invention.

[0015] Figure 9 is a perspective view of a dielectric sheet substrate in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

[0016] Figures 1-3 illustrate a method of forming a toroidal winding assembly 107 in accordance with one embodiment of the present invention. The method comprises: forming a longitudinal assembly 100 (Figure 1) having a first assembly end 106 and a second assembly end 108; bending longitudinal assembly 100 to form a generally toroidal assembly 105 (Figure 2); and bonding first assembly end 106 to second assembly end 108 to form toroidal winding assembly 107 (Figure 3).

[0017] Alternative embodiments of the invention may employ different methods of forming longitudinal assembly 100. As illustrated in Figure 1, one method of forming longitudinal assembly 100 comprises providing a winding core 102 comprising a core material that is substantially non-ferromagnetic and winding at least one electrical conductor 104 around winding core 102 to form longitudinal assembly 100. As defined herein, "substantially non-ferromagnetic" means having a relative magnetic permeability with respect to air in a range from about 1 to about 1.5. That the winding core be substantially non-ferromagnetic is important when toroidal winding assembly 107 is used as a current sensor. If the core material had a higher relative magnetic permeability, then any residual air gap left after bonding first assembly end 106 to second assembly end 108 would produce an asymmetry in the sensor's magnetic properties that would impair the sensor's ability to ignore ambient magnetic fields and thus reduce the sensor accuracy.

[0018] In a more specific embodiment, the core material comprises a core polymer which may be cured. Curing may be achieved by exposing the core polymer to a curing stimulus. Examples of curing stimuli include, but are not limited to, ultraviolet radiation, chemical curing agents, and heat. By way of example, but not limitation,

the core polymer may comprise about 100 parts of diglycidyl ether of bisphenol A and about 10 parts of diethylene triamine, mixed at a mixing temperature in a range from about 50 to about 70 degrees Celsius, then cured at a curing temperature of about 25 degrees Celsius. By way of another example, the core polymer may comprise a rubber cured by heat.

[0019] In another embodiment of the invention, longitudinal assembly 100 may be coated with a motion constraining material 109 (Figure 5) prior to bending. If electrical conductor 104 is wound with a uniform coil spacing, motion constraining material 109 serves to preserve the uniform coil spacing during bending. That the coils be uniformly spaced is important because asymmetry in the geometry of toroidal winding assembly 107 reduces sensor accuracy. In more specific embodiments, motion constraining material 109 may comprise a coating polymer which may be cured. Curing may be achieved by exposing the coating polymer to a curing stimulus. Examples of curing stimuli include, but are not limited to, ultraviolet radiation, chemical curing agents, and heat.

[0020] By way of more specific example, but not limitation, the coating polymer may comprise a mixture of gelatin and ammonium dichromate baked at a baking temperature in a range from about 50 to about 60 degrees Celsius, or solvent cast polychloroprene baked at a baking temperature in a range from about 25 to about 35 degrees Celsius, or solvent cast styrene-butadiene-styrene co-polymer baked at a baking temperature in a range from about 50 to about 75 degrees Celsius.

[0021] Regarding another embodiment of the invention, Figure 4 illustrates a method of forming longitudinal assembly 100 in which a spacing wire 120 is wound around winding core 102 abutting at least one electrical conductor 104. If electrical conductor 104 is wound with a uniform coil spacing, spacing wire 120 serves to preserve the uniform coil spacing during bending. After bending longitudinal assembly 100 to form generally toroidal assembly 105, spacing wire 120 is unwound. Alternative embodiments may use a plurality of spacing wires 120, a plurality of electrical conductors 104 or any combination thereof.

[0022] In some embodiments of the invention, winding core 102 may comprise a material so compliant as to be awkward to handle. Figure 5 illustrates a method of forming longitudinal assembly 100 in which, to facilitate handling, a stiffening rod 145 is inserted into a longitudinal hole 144 prior to winding at least one electrical conductor 104 around winding core 102. Stiffening rod 145 may be extracted after winding.

[0023] Regarding another embodiment of the invention, Figure 5 illustrates a method of forming longitudinal assembly 100 which comprises applying to winding core 102 a winding support layer 138 having a plurality of winding grooves 146 and winding at least one conductor 104 (not shown) in winding grooves 146. Winding support layer 138 aids in providing uniform coil spacing. In accordance with the embodiment of Figure 5, Figures 6 and 7 illustrate, respectively, bending longitudinal core 100 to form a generally toroidal assembly 105, and bonding first assembly end 106 to second assembly end 108 to form toroidal winding assembly 107.

[0024] In accordance with another embodiment of the invention, Figure 8 illustrates an alternative method of forming longitudinal assembly 100 by inserting winding core 102 into an outer shell 152 after winding at least one conductor 104 around winding core 102. Outer shell 152 is an alternative means of restraining any motion of electrical conductor 104 (Figure 1) during bending.

[0025] In a more specific embodiment of the invention in accordance with Figure 8, outer shell 152 comprises an outer shell material that contracts upon exposure to a contraction stimulus. For example, materials used for shrinkable tubing, such as polyvinyl chloride (PVC), polyolefin, neoprene, or polyvinylidene fluoride (PVDF), may be made to contract upon exposure to heat. After inserting winding core 102 into outer shell 152, outer shell 152 is exposed to the contraction stimulus to form longitudinal assembly 100. Contracted outer shell 152 in conjunction with winding core 102 serves to restrain any motion of electrical conductor 104 (not shown in Figure 8) during bending.

[0026] In another embodiment in accordance with the invention of Figure 8, motion of electrical conductor 104 (not shown) may be constrained by filling an annular gap 162 between winding core 102 and outer shell 152 with a filler material 164. In more specific embodiments, filler material 164 may comprise a filler polymer which may be cured. Curing may be achieved by exposing the filler polymer to a curing stimulus. Examples of curing stimuli include, but are not limited to, ultraviolet radiation, chemical curing agents, and heat. By way of example, but not limitation, the filler polymer may comprise solvent cast polychloroprene.

[0027] Figure 10 illustrates another method of forming a longitudinal assembly 100 in accordance with the present invention. A first pattern of electrically conducting strips 184 is produced on a first face 186 of a dielectric sheet substrate 174. Each of the electrically conducting strips 184 has a first strip end 188 and a second strip end 190 coinciding with a first sheet edge 176 and a second sheet edge 178, respectively. First sheet edge 176 is attached to second sheet edge 178 such that first strip end 188 of each electrically conducting strip 184 forms an electrically conductive junction with second strip end 190 of an adjacent one of electrically conducting strips 184. Joining each electrically conductive junction, for example, by soldering, forms longitudinal assembly 100. In another embodiment of the invention, a second pattern of electrically conducting strips 184 is produced on a second face (not shown) of dielectric sheet substrate 174, the second pattern forming a conducting coil inside a conducting coil formed by the first pattern.

[0028] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.